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BASELINE DOCUMENT REVIEW
FOR THE PROPOSED CHUITNA COAL MINE, ALASKA

FEBRUARY 8, 2016

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Executive Summary

Robinson Noble reviewed four documents related to the proposed Chuitna Coal Mine in Alaska to provide insight into the feasibility of the proposed mine operations, characterize potential impacts from mining, and identify weaknesses in the documents and propose measures to address the weaknesses. The reviewed documents included baseline reports on the surface water and groundwater systems, a water management plan for the mine, and a groundwater model report.

A number of deficiencies and potential problems were identified in the reports. In particular, there is great uncertainty into how much precipitation infiltrates as groundwater in the area of the mine. This, and other uncertainties, call into question the validity of the groundwater model, and as a result, the validity of the water management plan which is based on model results.

Specific conclusions and possible implications of the deficiencies in the documents include:

- Confusion about what is the actual amount of evapotranspiration and recharge at the mine site.
- Possible mis-representation of the streams' surface water-to-groundwater interaction in the model.
- Potentially poor groundwater model calibration due to lack of continuous water-level data.
- A possible incomplete understanding of the hydrogeologic system.
- Basing analyses involving groundwater quality in the main aquifer on water from only one well.
- The water management plan likely underestimates the amount of water that will need to be managed.
- Planned winter flows in the streams will, during mining, will likely be much higher than average pre-mining conditions.
- The model likely underestimates the amount of water that will be produced during mining.
- The areal extent of drawdown during mining is underrepresented.
- Predicted stream base flow reductions caused by the mining are not reliable.
- The model probably cannot reliably predict site-specific impacts.
- To accurately predict drawdown and impacts to streams, the model will likely need to be reconstructed.

Introduction

The United States Environmental Protection Agency (EPA) asked Robinson Noble, Inc. (Robinson Noble) to review four documents related to the proposed Chuitna Coal Mine near Cook Inlet in Alaska. The purpose of the review is to provide insight into the feasibility of the proposed mine operations, characterize potential project impacts, and identify weaknesses in the documented analyses and propose measures to address them.

The four documents reviewed are:

Riverside Technologies, inc., June 2009, *Chuitna Coal Project Surface Water Component Baseline Report – Final Draft (1982) through September 2008*

Riverside Technologies, inc., April 2010, *Chuitna Coal Project Groundwater Baseline Report – Draft 1982 through January 2010*

Tetra Tech, March 2013, *Revised Draft Water Management Plan Chuitna Coal Project*

Arcadis U.S., Inc., March 2013, *Groundwater Model Report Chuitna Coal Project*

The four reports were prepared for PacRim Coal, LP, the proponent of the proposed mine.

The Robinson Noble review was completed by Joseph E. Becker with assistance from F. Michael Krautkramer. Both are licensed hydrogeologists with more than 30 years of experience, including experience designing and constructing groundwater flow models.

The current mine plan calls for the digging and refilling of sequential excavations over a 25-year period. The proposed mine excavations would be as deep as 300 feet. Wells are planned to dewater the mine area and depressurize a deeper aquifer underneath the mine site. Mining plans call for the water produced by the wells, in addition to passive inflow of groundwater into the pit during mining, to be discharged outside the mine to three local streams to maintain stream flow downstream of the mine.

The specific objective of the document review is to evaluate the proponent's characterization of the aquifer drawdown zones and address whether the documents describe the extent of drawdown with enough precision to:

A. Accurately predict the maximum instantaneous groundwater yield volumes for each sequential excavation?

B. Assess the feasibility of sequencing the mining excavations to minimize project effects?

C. Assess the effects of aquifer drawdown on surface waters outside the mine's surface disturbance footprint?

D. Predict the aquifer recharge period for each sequential excavation?

Physical and Geologic Setting

The proposed mine is located in the Chuit River basin of south-central Alaska on the west side of Cook Inlet some 40 miles west of Anchorage. The proposed mine area is approximately 5,000 acres and is projected to yield 300 million metric tons of coal. Mining is proposed as an open-pit operation, conducted as a series of sequential excavations. The mine site is located north of the Chuit River within three tributary basins. The tributaries are Lone Creek, designated as stream 2002, stream 2003 (sometimes referred to as Middle Creek), and stream 2004. The majority of the proposed mining area is in the 2003 basin. All three streams will be impacted by the mining with decreased flows due to the planned dewatering. Additionally, with the mining occurring in the 2003 basin, a portion of stream 2003 will be physically removed by the mining and reconstructed during reclamation.

The geology of the mine site consists of semi-consolidated, coal-bearing rocks of the Tyonek Formation overlain by more recent, unconsolidated glacial and alluvial sediments. A glacial drift covers most of the area except along the streams where alluvium is found. Beneath the glacial drift, the Tyonek Formation contains a number of coal seams, including the mining target: the Blue, Red 3, Red 2, and Red 1 seams (listed from highest to lowest). Mudstone, siltstone, and sandstone interburden occurs between the seams. Beneath the Red 1 coal is a sand layer known as the Sub Red 1 Sand. This sand layer is separated from the overlying coal by a clay layer. Beneath the sand are additional, deeper coal seams and interburden.

Two primary aquifers are present within the geologic section. A water table aquifer exists in the glacial drift and alluvium. This aquifer is responsible for most of the base flow to the streams and forms an upper groundwater flow system. This system is separated from a lower, semi-confined to confined groundwater flow system that occurs in the Tyonek Formation. This lower system includes an aquifer in the Sub Red 1 Sand and groundwater present in the coal seams and interburden, particularly in a sand and gravel zone in the interburden between the Red 2 and Red 1 seams.

Document Review

Before addressing the four questions pertinent to the specific objective of the review, each of the four documents will be summarized and evaluated for accuracy and missing, unsupported, or conflicting information.

Chuitna Coal Project Surface Water Component Baseline Report – Final Draft (1982) through September 2008

This report was produced by Riverside Technologies, inc. (Riverside) in June 2009. The first several pages of the report provide background information on the geographic and physical setting of the mine site; the main portion of the report concerns the surface water system including descriptions of precipitation, stream flow, sediment load, and chemistry and water quality.

Report Overview and Evaluation

The surface water section of the report is based on data collected from the USGS from 1975 to 1986, the original baseline study for the mine site with data from July 1982 to August 1983, and more recent data collected through 2008. Riverside describes the monitoring network as evolving over time with stations added and removed for various reasons. In 2006, the network was reevaluated/redesigned to have 21 stations. At the end of the 2008 water year, the network included ten continuous stream gaging and temperature stations (including quarterly water quality), five limited monitoring stations (monthly data), and six water quality stations (collecting monthly streamflow in addition to water quality). Each station, historic and active (as of 2008), are described in the report and all relevant data is provided.

Our review of currently active station locations shows fairly good coverage. There are three current (at the time of the report) stations on the Chuit River – one upstream of the mine area, one immediately south of the mine area, and one downstream from the mine area. Stream 2004 has one station near the mine area and one downstream near the confluence with the Chuit River. Stream 2003 has five stations in the mine area and one near the confluence with the Chuit River[1]. Six "current" stations are on stream 2002 (Lone Creek), three in the headwaters

[1] The report references a map of station locations. The map was not initially provided for review. However, we obtained a copy of the map off the Chuitna SEIS Sharepoint Site moderated by AECOM. The surface

near the mine area, two east of the mine area, and one near the confluence with the Chuit River[2]. There are also four current stations on stream 40[3].

Riverside describes snow hydrology data collected in the vicinity of the mine site. Stations include one in the mine area and three shortly outside the lease area. They also describe two continuous reading precipitation gages installed in the area, one between Ladd Landing and Beluga and the other adjacent to the mine area. This second gage was, in 1983, moved to Lone Ridge northwest and above the mine site, a gage was added south of the mine on the coast at Shirleyville, and a gage was added southeast of the mine area at one of the Lone Creek stream gages (number 220). These three precipitation gages provide data on the effect of topography on rainfall. Eleven non-recording gages were also installed, but data from these gages did not correlate well with the continuously recording gages, and therefore, the data was not used in the analysis.

Data from the precipitation stations shows a strong orographic gradient where precipitation increases with elevation (see data for the Lone Creek and Lone Ridge stations in Table 3.3 and text at the bottom of page 3-10 of Riverside's report). Spatial variation in rainfall during the summer is reported as significant, resulting from localized, short duration storms. Riverside reports the original baseline study estimated precipitation at the mine site at 50 inches. Using precipitation data from the original baseline period, with 20 years of precipitation data at Beluga and snow course data (4 to 9 years depending on site), Riverside estimated an annual average precipitation of 44 inches at the mine site. Using data from the Matanuska Agricultural Experiment Station, located north of Anchorage, the nearest pan evaporation station in the state to the mine site, Riverside calculated a reasonable estimate of evapotranspiration (but not including sublimation) at the mine site at about 12.2 inches per year, or as Riverside notes, 27% of the average annual precipitation (see section 3.3.3, on page 3-11, of the report). This statement is particular relevant to the EPA's review study. Arcadis, in their modeling report, state that the baseline studies report 27% of precipitation is groundwater recharge (this issue is discussed later in our report).

Riverside used fairly standard methods to analyze collected stream gaging data. They report low flows typically occur in August and March (March being lower than August) and high flows occur in May or early June (due to snow melt) and late August to early September and occasionally in October (due to storms). Total spring runoff volume is greater than the late summer storm season, but individual peak discharges are larger in late summer. Base flow conditions are generally present from December through March. Mean daily streamflows on small perennial tributaries are 0.5 to 2 cfs during low flows and 40 to 150 cfs during high flows. Mean daily flows for moderate-sized streams (including 2002, 2003, and 2004) are 2 to 8 cfs during low flows and 350 to 850 cfs during high flows.

Watershed yields were calculated for basin areas above each continuous station. Data shows higher average annual yields for higher average elevations. Additionally, surface water/groundwater interaction was examined by comparing upstream and downstream gages on the same

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water station map, Map 3.2-1, has a date of 3/5/2007, nearly two years prior to the date of the report. This map of station locations indicates station 170, on the first tributary of stream 2003, tributary 200301, is an active station, but the report text indicates it is a historic station.

[2] The station map indicates one of these stations, number 205, is historic while the text says it is a current station.

[3] Stream 40 is in the basin immediately east of the 2002 basin. Three of the stations on stream 40 are mislabeled on the station map as active or inactive as compared to the text.

streams during low-flow periods (December through March) as described on page 3-26 of the report. Results show Lone Creek (stream 2002) is gaining in its middle reaches (where it has eroded through the coal sequence and Sub Red 1 Sand). The report also states the most upstream reaches of Lone Creek may be losing some water to the Sub Red 1 Sand or coal units.

However, Table 3.8 in the report, which shows corresponding gage data for the same time periods, does not show data to support the assertion that Lone Creek is losing water in its upstream reaches. The table does indicate, but the text does not mention, that the following stream reaches are all losing water: the lowest reach of 2004 (immediately above the confluence with the Chuit River), the lower reaches of 2003 (from near the confluence into the southern portion of the mine area)[4], and the lower reaches of Lone Creek (from near the confluence to east of the mine area).

Base flow separations were completed for the ten continuous gaging stations for the 1983 water year, but not for more recent data, and are described on page 3-29. Response times to precipitation events were analyzed, with times generally ranging from between one and four hours without much difference between wet and dry periods. From this, Riverside infers the area soils are consistently saturated and poorly draining (see page 3-31). Runoff analysis indicates that for the Chuit River basin, approximately 67% of total available snow-pack water becomes runoff. In the sub-basins, it ranged from 44 to 83%. The rest is lost to depression storage, evapotranspiration, and infiltration (recharge).

Riverside reports they made water balances for the streams (though the balances are not presented) which show streamflows increase in a downstream direction. They state, on page 3-42, the increases are largely from tributary inflow, but also from very gradual gains from near-surface groundwater inflow. However, significant inflow from springs and seeps is not evident in the immediate vicinity of the mine lease area. This statement at least partially conflicts with the data in Table 3.8 which shows losing conditions in the lower reaches of the three streams (as described above).

Presented temperature data show maximum stream temperatures in July to early August of up to 24° C, but average 11° to 16° C. Minimums are in the winter, down to -2° C, but average slightly below 0° to almost 3° C (station 128 on 2003 in the mine area consistently had warmer winter water, almost 3°; most other stations were at or slightly below 0°). Diurnal fluctuations in steam temperature are pronounced in summer and up to 8° C. Diurnal fluctuations are minimal in the winter.

Sediment sampling was conducted in 1982 and 1983 and not apparently after that. Suspended sediment loads were found to be low over a wide range of discharges on the smaller streams and no relationships with flow were found in these streams. Loads increased in the larger streams and regression equations were determined for the larger streams and the Chuit River. However, Riverside notes that few samples were collected at high flows, and since most sediment discharge occurs at high flows, the equations could be improved with more samples collected at higher flows.

Stream reach surveys were conducted on Lone Creek and stream 2003. Manning's coefficient values were computed and channel bed stability evaluated. The evaluation did not allow for a

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[4] Data from stations C141 and C180 indicates the creek is losing water; however, the data from stations C140 and C180 are less clear, indicating a loss in December, but neither a gain nor loss in January – March. This implies most of the loss is between C141 and C140 in the southern mine area.

sharp distinction between discharges with channel stability and instability, but did provide discharge values of "reasonable confidence" between stability and instability. Longitudinal profile surveys were done for the upper reaches of stream 2003 in 1983 for use in reclamation. Riverside notes conditions have been altered since the survey primarily due to beaver dam flooding.

Water quality sampling occurred in the original baseline study at 25 stations monthly and quarterly at 17 stations in the revised program. Results show surface waters have low conductivity, median pH values, and poor buffering capacity. There is little spatial or seasonal variation. The water is a bicarbonate water with relatively low sodium, calcium, and magnesium concentrations. Total dissolved solids and hardness are low. Concentrations of metals in the surface water are generally low. There are occasional water quality criteria exceedances for some metals in some samples, including iron and manganese. Exceedances for iron and manganese were highest in steams 2002 and 2003. These results are similar to and consistent with the groundwater results (as presented in the groundwater baseline study, discussed below).

Summary

This report provides critical information needed for the groundwater modeling study. Specifically, information of streamflows, gaining and losing reaches of the streams, calculations of Manning's coefficient values, etc. The main weakness of the report is the limited data records available. While some stream gaging stations have multiple years of record, others are more limited. The precipitation gage records are particularly limited. The analysis present could be improved by longer data records.

Noted problems include:

1. Inconsistency between the map of station locations and the listed active stations in the report. Based on the date of the map, it appears it is from an earlier draft of the report. It was either never updated, or we were unable to obtain the most recent copy.

2. While the report is clear on its statement that average annual evapotranspiration at the mine site is equal to 27% of precipitation, or 12.2 inches (section 3.3.3 of the report), it appears this statement may be misconstrued in the groundwater modeling study. Additionally, the estimate of evapotranspiration is 5 inches smaller than the estimate presented in Tetra Tech's water management plan.

3. The report correctly identifies an upper to middle reach of Lone Creek as gaining groundwater, it fails to describe the lower reaches of Lone Creek, stream 2003, and stream 2004 as losing reaches. Further, even though the presented data suggests large sections of these streams lose water (on Table 3.8), the report states that the "streams generally gained flow very gradually from near-surface groundwater inflow."

Possible Implications

Possible implications of the noted issues for the surface water baseline report include:

- confusion about what is the actual amount of evapotranspiration and recharge at the mine site, and

- possible mis-representation of the streams' surface water-to-groundwater interaction in the model.

Chuitna Coal Project Groundwater Baseline Report – Draft 1982 through January 2010

This report was published by Riverside Technologies, inc. in April 2010. The 16 pages of the report provide background information on the geographic, physical, and geologic setting of the mine site; the main portion of the report concerns the groundwater system including hydrostratigraphic unit descriptions, discussions of the local groundwater flow systems, and descriptions of the groundwater chemistry.

Report Overview and Evaluation

The introduction to Riverside's groundwater baseline report says it "represents a comprehensive collection of all groundwater hydrology and water quality data collection efforts performed in the project area between 1982 and December 2008." This must be a typographical error from an earlier draft because the report does, as its title suggest, contain data from 2009 and January 2010.

Like the surface water baseline report, Riverside (on page 2-4) estimates evapotranspiration at 12.2 inches per year, based on comparing the site to the most similar "in terms of elevation and coastal influence" evapotranspiration station in the state – the Matanuska Agricultural Experiment Station, which has an average annual pan evaporation rate of 17.4 inches per year. Riverside estimates the evapotranspiration at the subject site at 70% of the Matanuska rate.

Riverside notes that groundwater studies began in the early 1980s when Bechtel installed observation wells as part of a coal exploration program. Additional data was collected by Environmental Research & Technology, Inc. (ERT), Diamond Alaska Coal Company, and Riverside through 1986. No data was collected between 1986 and 2006.

In 2006, the 83 reported historic wells from these earlier studies were surveyed by Riverside. All but 13 were located, but many were damaged. Downhole video, natural gamma, and EM induction logs were made of all accessible wells – a total of 32 monitoring wells and 3 larger diameter test wells. Well casings and ground surfaces were surveyed to provide accurate locations and elevations and allow depths to water to be converted to groundwater elevations. Several damaged wells were repaired and three wells were drilled at the Ladd Landing portion of the site in 2006. Additionally, 18 shallow piezometers were drilled in the mine area in the fall of 2006 and completed in alluvium or glacial drift sediments. The report notes between July 2006 and December 2008, water levels were recorded at each well between 1 and 11 times.[5]

The report describes four hydrostratigraphic units: the Sub Red 1 Sand, Mineable Coal Sequence, Glacial Drift, and Alluvium. Thicknesses, transmissivities, and other hydrologic properties are described.

While broad descriptions are provided for the hydrostratigraphic units, in some cases, there is a general lack of data to support the descriptions. For example, concerning the transmissivity in the Sub Red 1 Sand, the report states: "Bechtel performed aquifer tests in the sand at two locations… Transmissivity estimates calculated from these tests were 300 and 1,800 gpd/ft… These values may be low, however, because the wells at the sites appeared to penetrate the aquifer zone only partially. The areal distribution of transmissivity of the Sub Red 1 Sand was estimated from short-term well recovery tests. Highest values occurred west of the permit area

[5] This statement again is probably left over from an earlier draft. Water level data was also collected in 2009 and January 2010.

and decreased eastward toward Lone Creek." Data to support this statement is provided in Appendix B-2. Yet the appendix only shows two recovery tests in the Sub Red 1 unit.

Additionally, the term hydrostratigraphic unit should be loosely interpreted for the report. A hydrostratigraphic unit is generally defined as being comprised of geologic units with similar hydrogeologic properties. More specifically, Seaber (1988) defines a hydrostratigraphic unit as "a body of rock distinguished and characterized by its porosity and permeability." In practical terms, hydrostratigraphic units are typically divided into aquifers and confining layers, since aquifers are permeable by nature and confining layers are not.

However, in Riverside's report, the hydrostratigraphic units as described generally do not separate aquifers and confining layers. For example, the report includes both the coal seams and the interburden above and between them in the same hydrostratigraphic unit: the Minable Coal Sequence. Yet, the report states: "there is some flow between the [coal] seams through the predominantly fine-grained interbeds but that (sic) the coal seams have a higher permeability compared to the interburden sediments." It further states "the interburden beds also generally act as aquitards providing partial confinement for flow within the coal seams." In more typical definitions of hydrostratigraphic units, aquitards (which are confining layers) would not be included in the same hydrostratigraphic unit as an aquifer except in the case of regional definitions. It should be noted, Arcadis does, to a certain extent, modify the hydrostratigraphic units for modeling purposes (see the groundwater modeling section below).

The same issue occurs for the glacial drift unit, which contains both "unsorted mixtures of clay to boulder-sized material" (glacial till), "lenticular bodies of well-sorted sand and gravel" (likely glacial outwash), and "occasional well-bedded lacustrine silts and clays" (glaciolacustrine deposits). Typically, till and glaciolacustrine deposits are confining layers and not included in the same hydrostratigraphic unit as glacial outwash. Granted, the report states "mapping and characterization of individual zones within the deposit are not practical."

Concerning the glacial drift, Riverside notes it is particularly heterogeneous, with transmissivities ranging from 4,500 to 250,000 gpd/ft. One particularly high permeability zone is noted in the east-central portion of the mine area. The report, on page 4-6, states "it seems likely that other highly permeable zones occur within this unit in the mine area." If other highly permeable zones do indeed exist, modeled predictions for the glacial drift could be inaccurate (this is discussed further in the review of the groundwater modeling report and the response to question A).

The report also states that peat deposits are present in depressions on the glacial drift and that drilling has found it is up to 23 feet thick. It is also present in the alluvial sediments. The role of the peat in the hydrologic system is not discussed.

In the report's description of the alluvial hydrostratigraphic unit, it states that while field data is not available, transmissivities in the alluvium are estimated to range from 3,000 to 50,000 gpd/ft with specific yields ranging up to 20 percent. No justification or support is given for these estimates.

Riverside examined available information on each well in the study area to determine the hydrostratigraphic unit each was completed in. They also estimated aquifer hydraulic properties at all wells with test data.[6] A summary table lists the number of water level measurements available for each well – though the table includes "flowing" as a water level when in reality it indicates the water level is higher than the measuring point rather than an actual measurement.

Based on observed water level elevations, Riverside conceptually divided groundwater flow into an upper (Alluvium and Glacial Drift), unconfined system and a lower (Mineable Coal Sequence and Sub Red 1 Sand), confined system. The report discusses the flow system in each of the hydrostratigraphic units and presents hydrographs for a number of wells in each unit. Discussions of confined/unconfined nature, flow directions, and generalized recharge of the flow systems for each unit appear reasonable based on the level of data available. However, the presented hydrographs, because of the scale used, are not very useful for analysis.

The remainder of the report discusses groundwater quality and chemistry. Riverside notes that many of the water samples collected from 2006-2010 have high turbidity and total suspended solids (TSS). They attribute this as probably being due to inadequate well construction and development. Consequently, two sets of water quality data are presented in the report, one with all the samples and one with only samples with turbidity below 50 NTU and TSS below 20 mg/l. Riverside believes the second selected data sets probably better represents naturally occurring water quality. We concur with this assertion.

Water quality is examined by hydrostratigraphic unit. Water quality sampling occurred at one well in the alluvial unit, one well in the glacial drift unit in the mine area, three glacial drift wells in the Ladd Landing area, three wells in the minable coal sequence unit, and two wells in the Sub Red 1 unit (see Section 5.4.2). The data, taken both by unit and as a whole, shows naturally occurring, elevated concentrations of iron and manganese, with occasional exceedances of other metals. Riverside notes that the results are very consistent with the water quality exceedances for the surface waters of the area. They also note that waters from all the hydrostratigraphic units are calcium bicarbonate waters, with increasing concentrations of sodium, calcium and magnesium with depth/residence time, and that the glacial drift and alluvial waters are similar to the surface water.

Summary

Similarly to the surface water report, this report includes important information for use in creating the groundwater model. However, it also suffers from a lack of data. The number of aquifer tests conducted and the amount of water level data collected in particular are lacking. The definition of hydrostratigraphic units, an important component of a conceptual model[7], and therefore, a numerical groundwater flow model, are not, in our opinion, sufficient for modeling.

Noted issues include:

1. There are a number of instances in the report where language from earlier drafts of the report should have been changed but wasn't.
2. There are occasional instances in the report of statements given without supporting data or with poorly presented data. For example, a transmissivity range is given for the

[6] We did not review the well information to estimate the accuracy of these determinations and estimations.
[7] Conceptual models define, but do not necessarily quantify, all the hydrologic components necessary to create a numerical groundwater flow model. They describe the character of the aquifers and confining layers, the sources of recharge, how groundwater discharges, and how water moves through the system.

alluvial sediments, but no justification is given as to why the range is believed appropriate. Statements are made concerning the well hydrographs, yet because of the scale chosen for the figures, the veracity of the statements could not be checked. Because most variations on water levels with a single well are likely tens of feet or less, the chosen scale of 1,000 feet totally masks any water level variations.

3. As with the surface water report, the estimated evapotranspiration conflicts with estimates made by Tetra Tech in the water management report.
4. Considering the scope of the Chuitna coal project, it is surprising that more water level data is not available. Spot measurements were made over a several-year period. However, no continuous long-term records are available. The study would have benefited from the installation of several pressure transducers and data loggers to create continuous water level records. Given that transducers were used for surface water stations, it is interesting that transducers were not also used for the groundwater monitoring wells. Seasonal variations in water levels in some wells are noted, but continuous records are not available to better evaluate the variations. Such records are also very helpful in conducting groundwater model calibration. We consider this a major deficiency.
5. Though described as hydrostratigraphic units, the units described in the report are not hydrostratigraphic units using the traditional definition of the term. Specifically, the units are not fully divided into aquifers and confining units. The definitions given in the report are not sufficient for use in a groundwater modeling project. Additionally, the possible role of the peat deposits in the hydrologic system are not described.
6. Water quality sampling only occurred in only a few wells. The number of wells sampled makes it difficult to determine true average background water quality conditions for the hydstratigraphic units. This is especially true for the alluvium and the glacial drift, each which only had one well sampled.

Possible Implications

Implications of the noted issues for the groundwater baseline report include:

- potentially poor groundwater model calibration due to lack of continuous water-level data for monitor wells in the mine area,
- a possible incomplete understanding of the hydrogeologic system, and
- basing any analyses involving system groundwater quality from the main aquifer on water from only one well.

Revised Draft, Water Management Plan, Chuitna Coal Project

The water management plan report was published by Tetra Tech in March 2013. The report describes the water balance for the mine area, planned water control structures and discharge outfalls, and the water management plan. Of most interest to this review project are the water balance and water management plan.

Report Overview and Evaluation

Following an introductory section, the report describes the water balance developed by Tetra Tech prior to making the water management plan. Monthly water balances were developed using site hydrogeology, projected groundwater pumping rates, and the projected mining plan.

Planning was done for the first 8 years of operation, as well as years 15, 22, and 26. Tetra Tech assumes the water balance and water management plan will be reviewed and modified as needed on 2.5- and 5-year permitting cycles.

A site-specific precipitation estimate is crucial to the water management plan. Since available precipitation records for the site were limited (two years available), Tetra Tech, as described in Section 2, elected to use a water-balance approach "to estimate precipitation based on the total water year yield from the 2003 drainage" using an equation where:

> Water Yield = Total Stream Flow = Base Flow + Runoff = Precipitation (including snowmelt) - Evapotranspiration - Deep Groundwater Recharge.

Tetra Tech used long-term stream flow measured on site, modified evaporation data from the Mantanuska station, and groundwater recharge and base flow estimates from the Arcadis groundwater model to estimate precipitation for the mine site. To check the sensitivity of the calculated precipitation estimates, they used an alternate computation with total stream flow (without the groundwater model data). Reportedly, the two methods produced similar results (within 5%).

For the stream flow data, they used data from the C180 gage near the outlet of stream 2003. Since C180 is outside the mine area, its record was "transposed" upstream to other stations in the mine area (that have too short of records to use directly) by using drainage area ratios.

For the evapotranspiration input, they used Matanuska weather station data. Long-term station data from 1948-2008 show an average annual evaporation of 13.48 inches after applying a standard pan evaporation coefficient of 0.7. Based on other studies, Tetra Tech added an additional 4 extra inches to account for plant evapotranspiration. This gives a total annual evapotranspiration rate of 17.5 inches (see Section 2.3). This is 5 inches greater than the evapotranspiration estimated by Riverside.

The groundwater model created by Arcadis was used to estimate the recharge component of the water-balance equation. Tetra Tech reports in Section 2.4 that the model shows 27% of precipitation recharging the glacial drift unit, and 97.2% of that is returned to stream base flow, leaving 2.8% as deep recharge. In our opinion, it is a bit of circular argument using results from the groundwater model to determine precipitation when one of the inputs to the model is recharge which is determined from precipitation.

They also used Arcadis' model for the stream base flow component, also described in Section 2.4. The model predicted annual base flow and monthly base flow was needed for the water management plan (to compute surface runoff). Tetra Tech estimated monthly base flow by using the smaller of the observed monthly stream flows or the average monthly model-generated base flow (the annual value divided by 12) for each month, and applying the differences (when actual stream flow was lower) to the other months (April, May and June). It is interesting that Tetra Tech decided to use groundwater model results for base flows rather than doing base flow separations on the actual stream flow data.

As a check of the method, Tetra Tech compared the computed precipitation values from the water balance to the actual precipitation recorded for water years 2007 and 2008 at the Lone Creek precipitation gage. Results were within 3%.

Once all the components of the water-balance equation were determined, it was used by Tetra Tech to compute precipitation estimates and runoff coefficients for wet, dry, and average years. Wet and dry years were defined as stream flows (at C180) one standard deviation above and below the mean. Using these, the average-year precipitation was calculated at 48.4 inches, wet as 51.3 inches, and dry as 43.6 inches. Then using the evapotranspiration estimates, runoff coefficients for undisturbed land were calculated. To differentiate runoff response from disturbed land, Tetra Tech estimated 80% of the evaporative loss would be eliminated (see the end of Section 2.5 on page 8 of the report). This methodology for disturbed land assumes that the decrease in evapotranspiration all goes to runoff and not recharge. In actuality, recharge may also increase, or decrease, depending on how compacted the disturbed land is.

Projected groundwater pumping rates (and residual pit inflow) were also needed by Tetra Tech to develop the water management plan. These were taken from the results of the groundwater model.

For the water management plan, Tetra Tech developed monthly high and low stream flow targets based on the C180 stream flow record. Ideally, augmented stream flows should not fall below a minimum target or be above a maximum target for any given month. The goal of establishing such targets for each month "was to provide a water management and discharge strategy that would augment stream flow in a manner that would resemble naturally occurring conditions." Targets were set for each month by examining the complete record for station C180 and, for each month, selecting the lowest and highest average monthly discharges on record for that particular month. This way, the targets represent actual flow values that have occurred in the past.

Monthly stream flow was estimated (using the water balance) for mining years 1 through 8 and years 15, 22, and 26. These were compared to the stream flow targets, predicted (modeled) reductions in base flows, and groundwater discharge rates. Analysis by Tetra Tech shows none of the predicted augmented stream flows for any of the three streams falls below the minimum flow targets. As reported on page 19 of the report, with some limited exceptions, all of which occur in the 2003 drainage, mining discharges do not increase predicted stream flows above upper targets "or beyond a reasonable flow regime threshold" in even the wet-year scenarios.

The limited exceptions cited mostly occur at gaging stations C140 and C141 and mostly in February and July. Tetra Tech reasons these high flow exceedances are not serious breach of the established targets because 1) the targets for February and July are considerably lower than targets for the shoulder months (January and March, and June and August) and 2) the targets for C140 and C141 may be low as an artifact of using C180 records to develop the targets.

Tetra Tech's rationale for the exceedances not being serious points out that their high flow targets in themselves may be problematic. Specifically, when discussing the February flows, Tetra Tech notes that "January and March records contain higher flows due to brief thawing periods in those months in some years." This suggests that perhaps the targets for the winter are too high, because high flows in January and March are only seen in some years and never in February. If high winter flows are uncommon, having targets based on those uncommon events probably defeats the purpose of having the augmented flow "resemble naturally occurring conditions."

They also report that total groundwater withdrawals exceed projected stream flow depletions in the three subject drainages for all mining years evaluated except years 19, 21, 24, 25, and 26. The maximum reported deficiency is 5.04 cfs in year 26, the year after mining concludes (and, therefore, would have no pumping). During mining, the largest deficiency is 1.02 cfs in year 25. To overcome these deficiencies, Tetra Tech notes that in years 15 through 25, additional water can be pumped from the mineable coal sequence and the Sub Red 1 Sand to augment stream flows as necessary. In year 26 and beyond, surface ponds and Sub Red 1 Sand wells can be pumped as needed.

The plan assumes pumped groundwater is of suitable quality for permitted discharge to the streams. This assumption is based on the Sub Red 1 Sand groundwater quality being, "in most cases, …better than that of the natural surface water" and the water quality of the glacial drift groundwater as being similar to that of the surface water.

Summary

Data from this report is not used in the creation of the groundwater model, rather the model supplies data for the analyses conducted by Tetra Tech for the report. The water management plan relies on accurate determinations of precipitation and groundwater discharge from the mine (both pumped and passive inflow). The issues raised by this report involve methodology and lack of precipitation data.

These include:

1. Precipitation data is key to how much water will need to be dealt with through the water management plan. Therefore, the lack of a long on-site precipitation record is a problem, which Tetra Tech attempts to solve by using a water-balance approach (in report Section 2). And while using a water-balance equation can be a powerful tool for determining hydrologic values, we find it unusual to use a water balance to determine precipitation amounts when it relies on using groundwater recharge as one of the known inputs, especially when the groundwater recharge is derived from a groundwater model and site-specific precipitation data already exists (granted, though, that data is limited to two years). Typically water-balance equations are used to solve recharge as the unknown. Groundwater recharge is a direct function of precipitation and an input to a groundwater model. If the precipitation is unknown, how can the groundwater recharge be known? The method used by Tetra Tech is especially called into question when considering the uncertainty in the recharge used in the model (see point 4 in the Summary section of the groundwater model report review below).

2. It is also curious that Tetra Tech used values derived from model results to determine stream base flows when stream flow data exists for which base flow separation techniques could be used, especially when a longer stream flow record than precipitation record is available. If there was a reason why the stream flow data was less reliable than model results for determining base flows, it is not given in the report.

3. Tetra Tech assumed that all the decrease in evapotranspiration on disturbed land would go to runoff (see the end of Section 2.5 on page 8 of their report). Depending on the nature of the disturbed land, some of the decrease in evapotranspiration may infiltrate as recharge. Alternatively, the nature of the disturbed land could lead to less recharge. Consideration should have been given to changes in recharge rather than just assuming all loss of evapotranspiration would result in an increase in runoff.

4. Further, in the discussion of evapotranspiration, Tetra Tech determines an annual evaporation of 13.5 inches and then adds an additional 4 inches as a plant transpiration factor, for a total of 17.5 inches. Yet, they assume on disturbed land, the evapotranspiration will decrease by 80% (or 14 inches). Assuming the disturbed land is barren of vegetation, this would allow for a decrease of 4 inches (by their own reasoning). Why should

the evaporation component of evapotranspiration decrease by 10 inches? More explanation is needed in the report.

5. Tetra Tech's estimate of evapotranspiration (on undisturbed land) is 40% higher than the previous estimates made by Riverside. The report could be improved by providing an explanation of the difference. The amount of evapotranspiration is a critical component in determining how much recharge to apply to the groundwater model.

6. The upper stream flow targets for the water management plan for January and March rely on, apparently, fairly rare melting events. For example, the January upper target is 53.7 cfs, an average January flow that reportedly happened at least once in the record for station C180. However, the mean January flow at the station is reported as 11.8 cfs. The high target is nearly four standard deviations above the mean, while the low target (3.0 cfs) is less than one standard deviation below the mean. Clearly, flows in the neighborhood of 50 cfs are rare in January.

Possible Implications

The issues found for the water management report have the following possible implications:

- the plan likely underestimates the amount of water that will need to be managed, and
- winter flows in the streams during mining will likely be much higher than average pre-mining conditions.

Chuitna Coal Project, Groundwater Model Report

The groundwater model report was produced by Arcadis in March 2013. The report describes the conceptual model and resultant groundwater model produced by Arcadis of the mine area. The model was used to simulate groundwater drawdowns and stream base flow depletions during the 25-year planned mining operation and recovery period (of 50 years) following active mining.

Report Overview and Evaluation

The groundwater model is based on a revised conceptual model derived from the conceptual model described by the 2010 Riverside groundwater baseline report and a 2011 supplemental well program used to address data gaps. Twelve new wells were installed in the 2011 program. The new Arcadis conceptual model divides the mineable coal sequence into three hydrogeologic units: The Upper Coal Sequence, Interburden, and Lower Coal Sequence; provides estimates of hydraulic conductivity for all hydrogeologic units; and evaluates flowing artesian conditions within the Sub Red 1 Sand south of the South Pit fault.

In total the Arcadis conceptual model identifies six hydrostratigraphic units[8], these are:

1. Glacial Drift and Alluvium: no aquifer testing was conducted for the alluvium, but percolation tests in test pits (by Shannon and Wilson, 2007) estimate hydraulic conductivities at 0.25 to 670 ft/day. Aquifer tests in the glacial drift show hydraulic conductivities between 1.3 and 440 ft/day. The higher number is from a permeable zone, and the lower number is believed to represent the bulk of the unit. In total, the hydraulic conductivity data comes from six well tests, three by Riverside and three by Arcadis.

[8] The text says hydrogeologic units, while the subhead for the section says hydrostratigraphic units.

2. Upper Mineable Coal Sequence: this includes the Green, Blue and Red 3 coal seams, each of which is discontinuous across the site (plus presumably the interburden between these three coal seams). Hydraulic conductivity values are estimated at $2.8x10^{-4}$ to 14 ft/day. Hydraulic conductivities are based on a single slug test by Arcadis and Riverside-reported "well tests" from an earlier study.

3. Interburden: fine grained sediments between the Red 3 and Red 2 coal seams. Hydraulic conductivities range from $8.5x10^{-5}$ to $1.1x10^{-3}$ ft/day, based on two slug tests by Arcadis.

4. Lower Mineable Coal Sequence: this unit includes the Red 2 and Red 1 coal seams, presumably the interburden between them, and a "lens of sand and gravel" found between the seams in the east and southeast portions of the site. The thickness of this lens ranges up to 150 feet or more. Additionally, there is a silty clay layer below the Red 1 with a thickness of 7 to 34 feet which may be part of the hydrostratigraphic unit[9]. Hydraulic conductivities of the coal are $5x10^{-3}$ to 0.4 ft/day. No hydraulic conductivities are given for the sand and gravel lens or the silt and clay layer. The coal conductivities are based on two slug tests by Arcadis.

5. Sub Red 1 Sand: a fine-grained sand found across the study area. Also mentioned in the unit description is the clay unit above it which acts as an aquitard. Presumably, though not clear in the report, the clay layer is included in the Lower Mineable Coal Sequence rather than the Sub Red 1 Sand unit[9]. Testing shows hydraulic conductivities of 1.3 to 19 ft/day. Conductivities are based on two tests by Riverside (2010) and two tests by Arcadis.

6. Lower Coal Sequence: this unit represents the Tyonek formation below the Sub Red 1 Sand. Arcadis believes it has similar properties to the mineable coal sequence, but no test data is available.

Concerning the hydrostratigraphic units, the Arcadis conceptual model improves upon the one by Riverside by splitting the mineable coal sequence into three units instead of leaving it as one. However, it's questionable whether the Glacial Drift and Alluvium should be lumped together. Further, the glacial drift contains both till and outwash, and should possibly be split. Also, the sand lens between the Red 2 and Red 1 seams is extensive, covering at least 1/3 of the mine area; it also could have been called out as a separate hydrostratigraphic unit. Figure 9 of the report, the calibrated hydraulic conductivity distribution for the model layer 4, shows this sand unit was assigned conductivities of 1 and 40 ft/day compared to values of 0.08 and 0.001 ft/day for the rest of the layer.

Arcadis' conceptual model also includes the Chuit and South Pit faults. These faults appear to be well documented and their inclusion in the conceptual model is appropriate.

The conceptual model divides the groundwater flow system into an upper and lower system akin to what was done by Riverside (2010): an upper, unconfined system in the Glacial Drift and

[9] It is unclear for the conceptual model section of the report whether this clay layer is included in the Lower Mineable Coal Sequence or the Sub Red 1 Sand. In the text, it is implied as being part of the Lower Mineable Coal Sequence, though also mentioned in the Sub Red 1 Sand description. In Appendix B of the report, a draft conceptual model update, the clay layer is only mentioned with the Sub Red 1 Sand.

Alluvium unit and a lower, semiconfined to confined system in the deeper units. The upper system receives recharge and discharges to nearby streams. Seasonal changes in water levels of up to five feet are present. A small amount of vertical leakage occurs, recharging deeper units. Well clusters installed by Arcadis in 2011 show an average downward vertical gradient of 0.43 ft/ft in the minable coal sequence. The lower system flows in a regional pattern generally from northwest to southeast. Seasonal water level changes are not present, except in some upper coal seams.

The report briefly describes hydrologic boundaries for the conceptual model. For the upper flow system, it states no-flow boundaries exist to the north, east and west represented by topographic divides (and expected nearby groundwater divides), which separate local flow into separate drainage basins. To the south, the Chuit River forms a discharge boundary. For the lower flow system, the report describes a recharge boundary on the west representing flow into the area from higher elevations west of the study area, a discharge boundary on the east representing flow out of the area, and no-flow boundaries in the north and south which represent regional groundwater flow lines.[10]

Understanding groundwater boundaries and correctly representing them in a groundwater flow model is critical to the model's success or failure. The available water level data for the glacial drift does suggest groundwater divides between the local basins. Data is available to show divides between basin 2003 and 2004 and 2002, but is missing for neighboring basins to the north and further west and east. This missing data is probably not much of a problem to the west and east, where the likely divides are fairly distant from the mine area (and the active area of the model), but the northern topographic divide is close to the mine area and a groundwater divide in this area has the potential of being affected with drawdown from the mine pumping. Water level data in the Scarp Creek basin would have been helpful to confirm the presence of a groundwater divide and more properly set the northern boundary for the Glacial Drift and Alluvium hydrostratigraphic unit.

The boundaries for the lower flow system are potentially more problematic. Model drawdown extends to the boundaries.[11] The northern and southern boundaries are represented in the model by no-flow boundaries, which simulate groundwater flow line paths. No-flow boundaries are used to simulate groundwater flow lines when those flow lines are far enough away from the active part of the model that drawdown will not reach them. However, when drawdown extends to these boundaries, it will alter the flow paths, and by doing so, it violates the conceptualization of no-flow.

Modeled drawdown also extends to the eastern and western boundaries of the lower flow system. These boundaries, a recharge boundary and a discharge boundary, are represented in the

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[10] In the conceptual model section, the report states north and south no-flow boundaries exist for all units in the lower flow system. However, when constructed, a general-head boundary was used for the southern boundary of the Sub Red 1 Sand layer. A general-head boundary is not a no-flow boundary and the use of one represents a break from the stated conceptual model.

[11] The full extent of modeled drawdown is difficult to determine from the report. Drawdown is presented on Figures 53 – 63, but only for areas with more than ten feet of drawdown. The text on page 30 discusses drawdown, but when discussing drawdown propagation, it is not clear what Arcadis considers a minimum (they imply their discussion of the extent of drawdown propagation is limited to ten feet or more based on a statement saying drawdown propagates across the northern model boundary in layer 5 "where the 10 ft. contour impinges on a short section of the boundary." Regardless, from the text on page 30 and Figure 63, it is evident that drawdown does reach the model boundaries for the lower system.

model by general-head boundary cells. Unlike no-flow boundaries, general-head boundaries do conceptually allow flow across, and therefore, are appropriate for use when drawdown does extend to the boundary. However, when drawdown does extend to these boundaries, the model is unable to determine how much further that drawdown would actually extend in the real world.

Arcadis' conceptual model discussion continues with a brief discussion of the recharge and discharge areas. They state that recharge to the upper flow system is from precipitation and discharge is to streams as base flow. Missing from the conceptual model is the fact that the streams may also contribute recharge to the upper system, particularly in the lower reaches.[12] Concerning the lower flow system, Arcadis says recharge occurs as regional groundwater inflow and as slow vertical leakage from the upper system and from precipitation where the mineable coal and sub Red 1 units outcrop. Discharge is mostly as underflow to the east, but also where the units outcrop along the upper reaches of Lone Creek. Concerning the precipitation which provides recharge to the upper system, the report specifically states on page 12: "as indicated in the baseline reports, site annual precipitation is on average 47 (44 to 50) inches/year of which approximately 12 inches/year (or 27%) recharge groundwater."

The report does not cite which baseline reports provide the precipitation and recharge numbers. Arcadis' reference section includes citations for two "baseline" reports: the *Chuitna Coal Project Geology Baseline Report* by Mine Engineers (2006) and the *Chuitna Coal Project Hydrology Component Baseline Report, Historical Data Summary* by Riverside Technologies, inc. (2010). Neither of these reports are subject to our review. However, it is possible the cited Riverside report is a combined volume of the groundwater and surface water baseline reports that are subject to our review rather than a totally different report.[13]

That said, neither of the Riverside baseline reports discusses the amount of recharge.[14] The 2010 groundwater baseline report states precipitation is "about 50 inches on the mine area" and estimates evapotranspiration (not recharge) at 12.2 inches. The 2009 surface water baseline report estimated average annual precipitation at 44 inches at the mine site. It further states: "water losses from evapotranspiration (not including sublimation) were estimated at 12.2 inches… or approximately 27 percent of the average annual precipitation at the Chuitna Coal Mine."

The conceptual model discussion in the Arcadis modeling report ends with a brief paragraph concerning the water budget. The report states the budget shows "groundwater recharge is 49.88 cfs, which considering the 46.72 square miles of the study area, results in an average recharge of approximately 11.9 inches/year." It continues "from the water budget we can calculate that the majority of groundwater recharge (48.47 cfs or 97.2%) exits the study area in the form of surface water baseflow. The remainder (1.4 cfs or 2.8%) recharges the lower groundwater system." No citation is given for the numbers presented in the water budget section, so

[12] While this statement is missing from the conceptual model section of the report, Arcadis' simulation of the streams in the model does allow recharge from the streams. The report, however, does not state whether such recharge actually occurs in the model or not.
[13] We did look at the Chuitna SEIS Sharepoint Site managed by AECOM for the stated Riverside hydrology component baseline report. There is such a report present, but it is dated March 2007. A quick review of that document did indeed show it is a combination of surface water and groundwater data and analyses and that it too, like the Riverside reports we reviewed, does not quantify recharge.
[14] The Riverside groundwater baseline report does discuss the sources of recharge for each hydrostratigraphic unit, but does not quantify the amount of recharge.

presumably they are results of modeling, and therefore, do not belong in the conceptual model section (but rather in the calibration section).

Following the conceptual model section, Arcadis discusses the numerical model code used, the type of MODFLOW input packages used, and details of the model construction. The model grid has spacing of 140 to 1,000 feet, with finer discretization used in the mine area and is presented on Figure 5 in the report. Unfortunately, the scale of the figure is too small to allow for easy comparison of the grid size to the sizes of the planned sequential mining excavations.

The model contains six layers representing the six hydrostratigraphic units in the conceptual model. Arcadis reports that layer thickness were based on the geologic model developed by Mine Engineers and updated by Pacrim Coal in 2011, except for the Sub Red 1 Sand and the Lower Coal Sequence units which were assigned uniform thicknesses of 30 and 300 feet respectively (see Section 3.4). Hydraulic properties for the layers were assigned using hydrogeologic zones, which were modified during calibration.

For layer 1, representing the Glacial Drift and Alluvium unit and the upper flow system, as previously mentioned, no-flow boundaries were used to simulate groundwater divides beneath the topographic divides in the west, north and east. The southern boundary was simulated by stream cells representing the Chuit River. Stream cells were also used to represent streams 2002, 2003, and 2004. Streambed conductance was set higher than the adjoining Glacial Drift and Alluvium conductivity. By doing so, Arcadis is making the assumption that the streambeds do not have significant thicknesses of materials finer than the underlying geologic units. There is no support given for this assumption (nor is the assumption even stated).

Recharge was applied to layer 1. Apparently it was initially applied uniformly over the area, but two separate recharge zones were identified during model calibration, a zone of 12.5 inches covering perhaps 80% of the active model and a zone of 8 inches in the Lone Creek valley and adjacent hills in southeast and central-east portions of the model. The strong orographic effect on precipitation, which should also occur in the recharge, was not applied in the model even though the active area of the model covers an elevation range of more than 1,250 feet (see Figure 15).

For the lower flow system (layers 2 through 6), general-head cells were assigned to the west and east model boundaries, allowing groundwater to enter and exit the model representing regional flow. No-flow boundaries were assigned on the north and south representing general west-east groundwater flow lines, except for the southern boundary of layer 5 (the Sub Red 1 Sand), for which general-head cells were used (see discussion above). Internal boundaries representing the two faults were simulated with the horizontal flow barrier package in layers 2 through 6.

Arcadis used water levels from 99 wells as steady-state calibration targets: 71 in the Glacial Drift/Alluvium, 9 in the Upper Mineable Coal Sequence, 5 in the Interburden, 6 in the Lower Mineable Coal Sequence, and 8 in the Sub Red 1 Sand unit (see Table 1 in the report). Dates of water levels range from the early 1980s to 2011. Well distribution is fair in the mine area, but weak outside the lease area.

Arcadis states on page 19 of their report that average base flows from December through March at area stream gaging stations were used for stream flow calibration targets. Nine gaging station locations were used: four on stream 2002, three on stream 2003, and two on stream 2004. By using winter base flows as calibration targets, the model underrepresents the steady-state base flow. Base flows in spring, summer and fall are higher than the base flows in the winter. The steady-state base flow should be the long-term average of all base flow, not just winter base flow. Arcadis stated that they did use hydrograph separation techniques to estimate base flow, but these yielded high base flow estimates (up to 41% higher than the winter base flow rates used) "that were not consistent with groundwater recharge estimates in the baseline hydrology report of approximately 27%." As previously noted, the baseline reports estimate evapotranspiration at 27% of the precipitation amount, not recharge. It is likely the hydrograph separation techniques would have yielded more accurate calibration targets than using the winter rates.

Steady-state calibration was conducted using PEST with further manual refinement. The calibration statistics meet standard limits. The calibration residual mean square (RMS) is less than 2% of the 853-foot range of calibration heads. All base flows were within 10% of the targets without significant positive or negative bias, except for station C128 which was at13.5%. The model also successfully produced the high vertical gradients seen in the field. However, it should be noted that while overall perhaps being adequately calibrated (ignoring the issues presented within this review), heads at individual wells can be tens of feet high or low. For example, as shown on Figure 25, in the mine area one well has a residual of positive 23 feet and another negative 15 feet.

Hydraulic conductivity and recharge zones following steady-state calibration are presented on Figures 6 – 11 and 15 in the report. Arcadis notes in the calibration section that "the low hydraulic vertical hydraulic conductivity assigned to the Sub Red 1 Sand hydrogeologic unit is meant to simulate the effect of the overlaying clay layer." This implies the clay layer was included in the Sub Red 1 unit rather than the overlying coal unit. Logically, it has properties more like the coal unit than the sand and, in our opinion, probably should have been included with the coal. Better yet, it could have been made a separate hydrostratigraphic unit/model layer rather than representing it quasi three dimensionally.[15]

In the Glacial Drift/Alluvium unit, the calibrated hydraulic conductivities range from 1.5 to 300 ft/day (see Figure 6). The highest conductivity zone is along the eastern portion of the active area of the model, filling much of the 2002 basin. This zone, with a conductivity of 300 ft/day, is labeled as alluvium, though much of the area is glacial drift instead of alluvium. Within the mine area, there is an area with a conductivity of 50 ft/day. Presumably this represents the more permeable zone noted in the baseline groundwater report. However, most of the drift is assigned the minimum value of 1.5 ft/day.

There are two recharge zones as described above. A portion of the high conductivity (300 ft/day) zone in layer 1 is also in the lower (8 inches) recharge zone. This seems counterintuitive, since higher conductivity materials should accept more recharge than lower conductivity materials. In fact, there does not appear to be any relationship of recharge to hydraulic conductivity, all hydraulic conductivity zones receive the same recharge (shown by comparing Figures 6 and 15).

[15] In numerical groundwater models, confining layers can be simulated three dimensionally by model layers with hydrologic properties (same as aquifer layers) or quasi three dimensionally by not including them in a model layer, but rather representing them via a smaller vertical hydraulic conductivity value in the adjoining aquifer.

Following the steady-state calibration, the model was subjected to a transient calibration. The period of July 1986 to January 1990, for which "continuous" water level records were available[16], was chosen as the calibration period. In applying recharge transiently, Arcadis estimated that 87% of recharge occurs in May through October and 12% from November through April. Generally, transient calibration results were fair compared to calibration target hydrographs.

Once calibrated, the model was run for a 26-year period representing one year of pre-mining dewatering and 25 years of mining according to the mine plan presented in Figure 36. Initial heads were obtained by running the model transiently for several years with seasonal recharge and no other stresses. As explained on page 24, mining was simulated by turning drain cells on and off according to the mine plan. Mine drain cells were assigned to the top five layers. Drain cells in the Sub Red 1 Sand unit were justified, according to Arcadis, because the unit will have to be depressurized for mining to proceed. Drain cell elevations were set at the bottom of each cell except in the Sub Red 1 Sand, where elevations were set to the bottom of the Red 1-2 coal unit. Haul roads were also simulated by drain cells, turned on and left on as mining progresses. These cells were in the top model layer only. Planned dewatering and depressurization is simulated in the model by wells. The wells were adjusted so that maximum well yields could be maintained.

In this application, drain cells conceptually represent passive groundwater inflow into the mine pit. This is appropriate for the units being removed. However, the Sub Red 1 Sand is not being removed or exposed by mining and will not directly contribute to passive inflow. Therefore, the use of drain cells for depressurization does not make sense conceptually. Conceptually, depressurization of the Sub Red 1 Sand unit should occur by wells rather than by using drain cells.

The use of drain cells in the Sub Red 1 has the effect of lowering the amount of depressurization needed from the pumping wells, so that the pumping wells need to pump less. The total amount of water produced from the Sub Red 1 Sand to achieve the necessary amount of depressurization in the model is the sum of the water produced by the drain cells combined with the pumping wells in the Sub Red 1. But in reality, all the depressurization will need to be accomplished by wells. In the real world, the amount of water needed to produce the same depressurization effect will be greater than the amount modeled (through the combination of drain cells and wells) because the pumping wells will not be located in the active excavation.[17] Therefore, the model underestimates the amount of water that will need to be produced from the Sub Red 1 Sand.

The next portion of the modeling report discusses the amount of water produced by the dewatering and depressurization wells and passive inflow. Dewatering wells were only placed in areas where saturated thicknesses were at least 50 feet because "it is expected that thinner thicknesses will not yield enough water to justify installing additional wells." Wells were placed ahead of mining with a general spacing of 500 to 1,000 feet. Depressurization wells were placed where head differentials were above 100 feet to maximize depressurization capacity.

[16] The continuous water level records are a series of spot measurements rather than continuous records obtained with transducers.

[17] The active excavation is where the passive inflow is occurring. Using a drain cell in the model in the active excavation has the same effect as using a pumping well in the model at the same location. By moving the wells outside the active excavation (like will occur in the real world), the wells will have to discharge at a greater rate to achieve the same amount of drawdown that a well in the active excavation would have.

The next section of the report discusses the predicted stream base flow reductions. In stream 2004, the maximum reduction is about 1 cfs occurring by year 22 of mining. In 2003, reductions are more significant (since this basin is the most affected by mining). The maximum reduction is about 4 cfs occurring by year 9. The maximum reduction in Lone Creek (2002) is about 1.4 cfs occurring near the end of mining. Reductions by stream reach are also discussed. Arcadis estimates the average total reduction will be approximately 3.8 cfs, while an average of 10.25 cfs will be produced by wells and through passive inflow.

Predicted drawdown is next discussed in the report. Simulated drawdown is provided on Figures 53 – 62 for year 8 and year 25. The figures only present a few drawdown contours, with a minimum contour of 10 feet. Drawdown in layer 1 reaches a maximum of 126 feet and reportedly does not propagate beyond stream 2004 to the west and Lone Creek to the east. Specifically, the report states "drawdown propagation across these surface water features does not occur. Groundwater contribution to baseflow from the adjoining (unmined) area will continue throughout the mine life." Drawdown in layer 5 (the Sub Red 1 Sand) reaches 547 feet and occurs in all directions reaching the west, east, south and north model boundaries.

Arcadis also presents the "maximum extent of drawdown propagation at the water table" and maximum drawdown extents for the Upper Mineable Coal, the Lower Mineable Coal, and the Sub Red 1 Sand. These presentations (Figure 63), however, only show the maximum extent of the 10-foot drawdown contour for the four units. Arcadis notes that for the water table, the maximum extent of the 10-foot contour is mostly contained in the mine lease area, with only about 50 acres outside the southern lease boundary.

This presentation is somewhat misleading. First, the ten-foot drawdown contour is not the maximum extent of drawdown, the zero-foot contour is[18]. Second, the unstated assumption in the report is that drawdowns less than ten feet are not a serious impact. Whether drawdowns less than ten feet are serious impacts or not is subjective and depends on factors such as saturated thickness, well screen depth, etc.

Following the mining simulation, the report describes a post-mining simulation during which all well and drain cells were turned off and normal seasonal recharge was applied. The simulation was run for 50 years. Stream bed elevations in the mined area were set 5 to 30 feet higher to reflect new post-mining topography. Hydraulic properties of the glacial drift backfill "are expected to be similar to those before mining" and, therefore, were not modified for the post-mining simulation (see page 32 of the report). However, hydraulic conductivities of the backfill in the mineable coal and interburden layers were increased, mostly because of the large sand and gravel lens in the Lower Mineable Coal unit being mixed in the backfill. The Chuitna and South Pit faults were removed from the model in the mine area for layers 2 through 4 (they are already not present in layer 1). The assumption that the hydrologic properties of undisturbed glacial drift and glacial-drift backfill being identical is questionable and is discussed further below in the Summary section.

The report continues with a discussion of post-mining water levels and residual long-term drawdown. As modeled, Arcadis states on page 33 that "in general, water levels within all hydrogeologic units within the mine area will fully recover by year 50 without supplemental measures." However, the presented hydrographs show decreases in water levels in some glacial drift and

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[18] It can be difficult to locate the zero-foot contour. When presenting or discussing drawdown extent, we typically use the one-foot drawdown as a proxy for the extent of drawdown.

alluvial wells, some Red 3 Coal wells, and in all Sub Red 1 Sand wells, as well as increases in some glacial drift and alluvial wells, in some Red 3 Coal wells, and in all interburden and Red 1 or 2 wells. Arcadis goes on to say that long-term post-mining water levels will decrease in the eastern mine area (Figure 70 shows declines up to 65 feet) and be higher in the western mine area (by up to 45 feet). Post-mining base flows are predicted to recover to pre-mining levels in basin 2004, decrease by 0.3 cfs in basin 2002, and increase by 0.2 cfs in basin 2003.

The term "full recovery" is not defined, but it seems to be inconsistent with long-term declines of up to 65 feet. Additionally, it is likely water levels in the Sub Red 1 Sand will also never fully recover (as shown by the hydrographs on Figure 69) due to a lower vertical gradient caused by the decline in water levels in the units above it.

The final section of the report, except for a summary and conclusions, discusses a sensitivity analysis of the model. In total, 14 sensitivity runs were made looking at changes in hydraulic properties of the Glacial Drift/Alluvium, the Lower Mineable Coal Sequence, the Interburden, and the backfill, and by the removal of the faults and changes in recharge.

Arcadis reports the model during mining is not very sensitive to changes in hydraulic parameters for the glacial drift unit, but after mining, increases in hydraulic conductivity and decreases in storage shorten the time for full recovery while the opposite increase it (yet it is still achieved by year 60). Similarly, increases in hydraulic conductivity and decreases in storage result in less drawdown, while the opposite results in more.

Their analysis of the recharge sensitivity was only for mine-induced base flow reductions. For the recharge sensitivity run, the recharge was reduced to 44% of normal during years 24 and 25. Arcadis notes that under natural conditions, such a 2-year drought would significantly reduce base flows which would take 10 years to recover. They subtract this "natural" effect from the model results to look at that the mining-induced effect of the 2-year drought. The net effect of the 2-year drought is to delay mining-induced base flow reductions by 2 years.

They report that base flows are not very sensitive to the mineable coal and interburden hydraulic conductivities during mining, nor to the removal of the faults. Post mining, decreases in hydraulic conductivity shorten recovery time and increases delay recovery (which still occurs by year 75).

The sensitivity runs which examined backfill hydraulic conductivity were conducted by instantaneously changing the conductivity at the start of the post-mining period. This causes pronounced changes to stream base flows (and recovering drawdowns) that are not wholly related to the parameter change, but rather to the equilibrium period for the system to adjust to the instantaneous change. The runs found decreased conductivity in the west backfill and increased conductivity in the east backfill shortens the time for recovery, while the opposite lengthens recovery time (still mostly achieved by year 75).

Summary

Overall, the Arcadis groundwater modeling report is relatively short on text and heavy on figures. Many assumptions are not described (or even mentioned) or supported with documentation or citations. Some of the figures are difficult to use in determining the validity of the model because of the scale they are presented at (two examples: 1) on the cross sections, Figures 12 and 13, it is impossible to discern any detail, and 2), the model grid scale on Figure 5 is too small to compare grid size to the sequential mining excavation sizes). Additionally, there are several errors or debatable practices used that call model results into question. Perhaps the largest of these is the question of whether the proper recharge was applied to the model (see point 4 below).

Specific issues include:

1. Hydrologic properties used for the model are based on relatively small amounts of data. For example, the hydraulic conductivity for the Glacial Drift and Alluvium unit (which has, by far, more wells than any other unit) is based on only six well tests, while the hydraulic conductivity of the Lower Mineable Coal Sequence is only based on two slug tests. Further, the sand and gravel lens within the Lower Mineable Coal Sequence, which plays an important role in the hydrogeology of the mine area, apparently was not tested.

2. Arcadis' conceptual model improves on the earlier Riverside model by splitting the mineable coal sequence into three hydrostratigraphic units instead of one. However, there still is some mixing of aquifers and confining units in the same hydrostratigraphic units. The conceptual model could have been improved by separating out the extensive sand and gravel lens between the Red 2 and Red 1 coal seams as its own hydrostratigraphic unit. Similarly, the clay confining layer above the Sub Red 1 Sand could have been separated out as a hydrostratigraphic unit. As presented, the text is unclear whether this clay is in the Lower Mineable Coal Sequence unit or the Sub Red 1 Sand unit.

3. There are also some issues with the boundaries in the conceptual model. For the upper flow system, north, west and east boundaries are defined as groundwater divides. These divides are assumed to exist under the topographic divides separating the area's stream basins, but there is a lack of data to fully substantiate this assumption. In particular, the northern topographic divide, separating the 2002 basin from the Scarp Creek basin is fairly close to the active mine area. Water level data in the Scarp Creek basin could help establish the exact location of the groundwater divide between the two basins. And while the conceptual definition of the boundaries in the lower flow system is fine, there is some issue with the implementation of these boundaries in the model (see point 11, below).

4. Perhaps the most troubling issue with the model concerns recharge. In the conceptual model section of the report, Arcadis cites the baseline reports as determining the recharge to the mine site as 12 inches per year or 27% of precipitation (see Section 2.5). Yet, the baseline reports we reviewed do not make such a statement. The Riverside surface water baseline states the evapotranspiration, not recharge, is about 12 inches or 27% of precipitation. The Riverside groundwater baseline report also states that evapotranspiration is about 12 inches (but does not mention the 27% figure). Neither report discusses the amount of recharge. Thus, it appears that Arcadis used a recharge number that has no supporting documentation or analysis. This calls into question the entire model calibration, and therefore, also all model results.

   Recharge is a function of the amount of precipitation and the ability of the surface soils to infiltrate the precipitation. Concerning the amount of precipitation, Riverside documents a strong orographic gradient where precipitation increases as elevation increases. The orographic effect is well shown in Table 3.3 of Riverside's surface water baseline report, which shows the average monthly precipitation at the Lone Creek precipitation gage (elevation 600 feet) was 2.53 inches in July through September 1983 and 3.56

inches at the Lone Ridge gage (elevation 1,500 feet) over the same time period. Consequently, there should also be a strong orographic gradient for recharge, also increasing with elevation (assuming a consistent hydrostratigraphic unit, which is the case here). Yet, Arcadis used only two recharge zones (see Figure 15). The main zone, with 12.5 inches of recharge, exists at the lowest elevations in the active area of the model (under 250 feet) and the highest areas (above 1,500 feet and are, coincidently, on Lone Ridge).

Infiltration capability is partially a function of the hydraulic conductivity of the surface geology such that normally there is a strong correlation between surface geology and recharge amount. Yet in the Arcadis model, there is no such correlation. There are two recharge zones. Most of the modeled area has a value of 12.5 inches per year, even though hydraulic conductivities for this area vary between 1.5 and 300 feet/day. The rest of the modeled area has a recharge of 8 inches – perhaps 90% of which has a hydraulic conductivity of 300 feet/day.

Additionally, the steady-state model was calibrated to base flows that were probably too low (see point 7 below). This implies that the model recharge was also too low. If higher base flows were used for calibration, the amount of recharge would need to be increased.

So there are several issues that make the recharge used by Arcadis questionable. And if it is questionable, it also makes the precipitation estimates developed by Tetra Tech in the water management plan questionable. Tetra Tech used a water-balance equation to estimate precipitation. In the equation, precipitation is calculated as total stream flow plus evapotranspiration and deep groundwater recharge. The groundwater recharge term used in their equation was determined from "a calibrated groundwater model" by Arcadis, 2012. The reference section shows the 2012 Arcadis report is titled Chuitna Coal Project; Groundwater Model Report (this is likely the draft report of the Arcadis modeling report we reviewed). Specifically, Tetra Tech states "the calibrated model indicated that 27% of average precipitation recharges the Glacial Drift unit."

5. Though the model's water balance is briefly discussed in the conceptual model section of the report, a complete model water balance by model layer is not presented (see Table 4). Without a water balance, it is not possible to confirm if the numerical model properly reflects the conceptual model.

6. The steady-state model was calibrated to water level targets. Ideally, water level targets for a steady-state calibration will be average water levels from long-term, time-synchronous records at many wells randomly scattered throughout the area of interest. In this case, while there are many wells, they are not randomly scattered, especially in a vertical sense. Of the 99 wells used as water level targets, 72% are in model layer 1. Additionally, few of the wells have long-term records or time-synchronous records. Most targets were based on water levels measured on a single day or during a single month.[19]

7. The steady-state model was also calibrated to stream base flows. However, Arcadis used winter base flows as calibration targets rather than average base flows (see report page 19). Therefore, the calibrated model underrepresents the steady-state base flow. Arcadis stated that they did use hydrograph separation techniques to estimate base

[19] The table of calibration water levels presented in the Arcadis report lists "measurement date", but rather than days, only months or years are listed.

flow, but these yielded high base flow estimates "that were not consistent with groundwater recharge estimates in the baseline hydrology report of approximately 27%." Again, the unsupported and likely erroneous assertion that 27% of precipitation goes to recharge plays a factor. Here, it prevented Arcadis from possibly using a more accurate base flow calibration target. The implication of having the model calibrated to lower base flows than the true steady-state values is that the applied recharge in the model was too low (higher steady-state base flows would require a higher amount of steady-state recharge).

8. For the predictive simulation, mining was simulated by turning drain cells on representing an excavation and off when the excavation was subsequently backfilled. Drain cells were assigned not only to the layers being removed for mining, but also to the Sub Red 1 Sand (model layer 5) even though it is not being excavated (see report page 24). It is conceptually incorrect to use drain cells to represent depressurization of the Sub Red 1 Sand during mining. The use of drain cells in the Sub Red 1 has the effect of lowering the amount of depressurization needed from the Sub Red 1 Sand extraction wells, so that the wells need to pump less. Therefore, the model underestimates the amount of water that will need to be produced from the Sub Red 1 Sand and, consequently then, the total amount of water produced by the mining process. From our review, it is not possible to determine how large this underestimation is.

9. For the predictive simulations, there is no discussion of stress periods and time steps used. The report says "seasonal recharge" was applied, but it is not clear if this was done using monthly, bi-monthly, or quarterly stress periods. To meet the objectives of the water management plan, monthly stress periods were needed, and were possibly used, though based on the modeling report, we cannot be certain[20].

10. Wells were modeled in the Glacial Drift and Alluvium unit during the predictive simulation to represent dewatering necessary for each sequential excavation. The number of wells and production rates for the dewatering wells is probably appropriate within the certainty level of the model (assuming the problems discussed above are not important). However, a significant uncertainty exists which could cause inaccurate estimates for the amount of dewatering needed. This uncertainty mainly effects the Glacial Drift/Alluvium unit. One higher permeability zone was identified in the glacial drift (in the eastern mine area). However, additional higher permeability zones may be present (the Riverside groundwater baseline report says such zones are likely) or the size of the known higher permeability zone may be larger than modeled. In either case, additional dewatering may be required beyond what was modeled and passive inflows may be larger than predicted.

    This issue can be examined through a sensitivity analysis. The sensitivity analysis presented in the report did not specifically look at dewatering volumes. But it did examine drawdown, which can be used as a rough proxy for dewatering production (if a particular sensitivity run produces less drawdown, a higher production rate will be needed to achieve the same amount of dewatering). Two sensitivity runs were made changing the hydraulic conductivity of the glacial drift unit – one doubling it and one halving it. These two runs had the effect of significantly decreasing and significantly increasing the

[20] And if used, they probably were not used in the simulations used by Tetra Tech to develop the water management plan since Tetra Tech describes only annual base flows from the model being available.

amount of drawdown in certain areas of the mine (see results for sensitivity runs 1 and 2 on Figure 82). This suggests that the production rates required to produce the proper amount of dewatering are fairly sensitive to this parameter, and therefore, uncertainty exists as to how much dewatering will actually be needed.

11. For the predictive simulation, the "maximum" extent of drawdown is presented on Figures 63a – 63d which only show the area subject to ten feet or more of drawdown. This, most likely, considerably underrepresents the area where drawdown occurs and presents an unwritten assumption that drawdown less than ten feet is not significant.

    One of the implications of this drawdown presentation is that the extent of drawdown at the model boundaries cannot be assessed. In cases where no-flow boundaries represent groundwater divides and groundwater flow lines, drawdown should not reach the boundaries, otherwise the boundaries are conceptually violated.

    Even with the poor drawdown presentation, it appears drawdown in the Lower Mineable Coal and the Sub Red 1 Sand do reach such boundaries, indicating the model is likely improperly predicting drawdown for these two units. The drawdown presentation does not allow for determination if drawdown reaches the model boundaries for the Upper Mineable Coal or the Interburden units but the text states it does. The text further states drawdown does not reach the model boundaries for the Glacial Drift/Alluvium unit, but this cannot be confirmed by the maximum extent of drawdown figure for the unit.

    Since the Lower Mineable Coal unit has a relatively low permeability (except for the zone of permeable sand), the modeling error of drawdown reaching no-flow boundaries may not be overly important (assuming the zone of permeable sand in the unit, or a similar undetected zone, does not exist at a model boundary). In the case of the Sub Red 1 Sand, only the northern boundary is a no-flow boundary (the others are general-head boundaries, which can conceptually have drawdown reflected across). The report states that drawdown does reach the northern boundary, but implies this model error is not important because the unit becomes unsaturated in that area (report pages 30 and 31). However, if drawdown in the unit was to actually occur in the real world in this area north of the mine, groundwater from the northern side of the boundary would flow into the unsaturated area. The result would be that additional water would need to be pumped to have the same depressurizing effect and drawdown would extend further to the north past the boundary. Further, because the Sub Red 1 Sand is closer to the surface in the northern portion of the area, it's possible the unit crops out in the Scarp Creek basin north of the mine area (similar to how it does in basin 2002). In that case, drawdown in that area could reduce stream flows in that basin.

12. In the post-mining simulation, Arcadis assumes the glacial drift backfill has the same hydraulic properties as undisturbed glacial drift (see report page 33). We are very skeptical about this assumption (as was EPA reviewer Edmond). Arcadis defends the assertion by citing a paper by Straskraba[21]. And in the review comments, they further defend it by citing the results of their model sensitivity study. The cited paper states that most studies on the subject conclude that hydraulic properties in replaced spoils are similar, but

[21] Straskraba, 1986, Groundwater Recovery Problems Associated with Open Pit Reclamation in the Western USA, International Journal of Mine Water, Volume 5 (4), p 45-56

less homogeneous, “when compared to pre-mining properties of sandstone and coal aquifers.” Further, it says that while pre- and post-mining flow systems are “not substantially changed,” the “original coal and sandstone aquifer have secondary permeability characteristic and the spoils have predominately primary permeability characteristics.” The studies reviewed by Straskraba are from the western United States.

There are several important issues here. First, it is probable that glacial drift was not a significant portion of the overburden in most the western US coal mines studied since glacial drift is only common in the northern states. Second, Straskraba’s statement is about “sandstone and coal aquifers” not glacial drift overburden.

Working in the Puget Sound region of Washington State, we are very familiar with the general properties of glacial drift. It consists of a wide range of unconsolidated sediments, some with low permeability and some with high permeability. In our opinion, removing and then backfilling of glacial drift will generally result in an increase in hydraulic conductivity for the unit as a whole. It is also likely that the vertical hydraulic conductivity will increase even to a greater extent because the unit will become more homogeneous. The result should be to increase the recharge rate into the backfilled glacial drift when compared to pre-mining conditions.

The Arcadis sensitivity study showed that total base flow reductions are not very sensitive to increases or decreases in glacial drift hydraulic conductivity. And this is not surprising, because conceptually, with much lower conductivity materials below the glacial drift, groundwater will still preferentially flow horizontally through the drift to the streams. However, Arcadis is predicting the post-mining hydraulic conductivity of the units below the glacial drift will increase. And while the sensitivity study did look at individually increasing the hydraulic conductivity in the lower units (both as undisturbed material and as backfill), it did not look at a scenario with the hydraulic conductivity increased in the glacial drift and the lower units (above the Sub Red 1 Sand) together. Conceptually, when the hydraulic conductivity of the glacial drift and the lower units are both increased, the leakage from the glacial drift into the lower units will increase and less water should be discharged to the streams.

Overall, the uncertainty created by the nature of the hydraulic conductivity changes in backfill, both in the glacial drift and the lower units, make conclusions about the changes in base flow speculative.

13. One thing the sensitivity analysis did show is that the model is very sensitive to recharge (see results from sensitivity run 5 on Figure 81[22]). As noted above, there is a question of whether the proper amount of recharge was applied to the model. If in fact the applied amount of recharge is incorrect, due to the model’s sensitivity to recharge, it is likely the model is improperly calibrated and the predictive results incorrect.

Possible Implications

Implications of the noted issues with the groundwater modeling report possibly include:

[22] The title of Figure 81 implies it only has results from sensitivity runs 1 – 4, but (as indicated by the legend) the light blue line is from sensitivity run 5 which investigated recharge).

- several potential flaws in the model indicate it likely underestimates the amount of water that will be produced during mining,
- the report underrepresents the areal extent of drawdown during mining,
- base flow reductions predicted by the model are not reliable,
- the model probably cannot reliability predict site-specific impacts, and
- to accurately predict drawdown and impacts to streams, the model will likely need to be reconstructed.

Specific Question Response

As a result of the document review, the EPA asked Robinson Noble to specifically address whether the reviewed documents describe the geographic extent of aquifer drawdown areas with enough precision to:

A. Accurately predict the maximum instantaneous groundwater yield volumes for each sequential excavation?

B. Assess the feasibility of sequencing the mining excavations to minimize project effects?

C. Assess the effects of aquifer drawdown on surface waters outside the mine's surface disturbance footprint?

D. Predict the aquifer recharge period for each sequential excavation?

Predicting Maximum Groundwater Yield (Question A)

The first question to be addressed is whether the analyses and results presented in the reviewed documents can accurately predict the maximum instantaneous groundwater yield volumes for each sequential excavation. In our opinion, for several reasons detailed below, the short answer is no.

Scale of Model Detail

Because the specific mining excavations are very site specific, even assuming the model was properly calibrated, the model would need to be more detailed than it is to accurately predict the maximum groundwater yields resultant from each sequential excavation. Proposed excavations are relatively small compared to the overall size of the model, and while the model grid spacing may or may not be sufficiently small to adequately represent the individual excavations, model input needs to be on a similar scale as the excavation sizes to provide accurate results for individual excavations. There are two major areas of concern: the detail in the applied recharge zones and the uncertainty in the hydraulic property distribution of the Glacial Drift and Alluvium unit.

There are many questions whether the proper recharge has been applied to the model. Regardless of these and assuming the recharge numbers are correct, an average of 11.9 inches per year of recharge was applied to the model. This recharge was applied in only two different zones: a large zone of 12.5 inches/year and a smaller zone of 8.0 inches/year (see Figure 15 in the Arcadis report). Such a distribution is fine if the goal of the model was to determine overall effects of the mine. However, when the goal of the model is to determine very site-specific effects (such as the response to a single excavation), the recharge distribution is not detailed enough.

We know the recharge distribution is not uniformly 12.5 inches over the majority of the model area. Several factors affect recharge rates including: precipitation rate, type and density of vegetation, and the infiltration rate of the soils and surface geology. Riverside (2009, p. 3-10) documents a large orographic effect where precipitation increases with elevation. All other things being equal, there should be an increase in recharge rate with elevation because of the orographic effect considering the active model area has an elevation range of approximately 1,250 feet.

The entire active area is covered by the Glacial Drift and Alluvium unit. Infiltration rate is related to a material's hydraulic conductivity. In the model, the Glacial Drift and Alluvium unit is assigned hydraulic conductivities ranging from 1.5 to 300 ft/day. This wide variation in hydraulic conductivity should be reflected in the recharge rates, but it is not.

The orographic effect on recharge and the differing infiltration rates resultant from differing hydraulic conductivities result in a spatial variation in recharge that is not reflected in the model. Without this detail in recharge variation, the model cannot accurately predict groundwater yield volumes for each excavation.

The other factor is uncertainty in the hydrologic properties of the Glacial Drift and Alluvium unit. Glacial drift generally consists of a number of different sediment types, which can broadly be classified as glacial till, glacial outwash, and glacial lacustrine deposits. Riverside (2010, p. 4-6) notes that all three sediment types are present in the glacial drift of the study area. Similarly, alluvial deposits also vary widely in sediment type, generally falling into coarse-grained channel deposits and fine-grained overbank or floodplain deposits. Again, Riverside (2010, p. 4-7) notes both sediment types are present in the alluvium. These varying sediment types can have a wide range of horizontal and vertical hydraulic conductivities, with the sediments with large fine-grained content (such as till and lacustrine and overbank deposits) having hydraulic conductivities generally under 1 ft/day and often several orders of magnitude lower. On the other hand, the sediments with fewer fines, such as outwash and channel deposits, have hydraulic conductivities typically over 10 ft/day and very often between 100 and 1,000 ft/day. The result is, as a group, glacial and alluvial sediments have a very broad range of permeabilities.

Ideally, the fine-grained dominated sediments and the coarse-grained dominated sediments will be divided into separate hydrostratigraphic units because one represents a confining layer and the other an aquifer. This did not occur in the groundwater model; all are represented within the single Glacial Drift and Alluvium hydrostratigraphic unit. There is some differentiation in the modeled unit – glacial drift is assigned hydraulic conductivities between 1.5 and 50 ft/day and the alluvium is given hydraulic conductivities of 20 or 300 ft/day[23]. Yet the assigned hydraulic conductivity zones are quite broad. In the glacial drift, there are two small zones with hydraulic conductivities of 20 and 50 ft/day, while the vast majority (we estimate approximately 90%) is given values of 1.5 or 2 ft/day.

Riverside (2010, p. 4-6) notes one highly permeable zone in the glacial drift was found in the eastern portion of the mine area (likely the 50 ft/day zone in the model), but states "it seems

[23] Figure 6 of the groundwater model report shows alluvium zones with this range. The accompanying table, however, lists alluvium only at 300 ft/day.

likely that other highly permeable zones occur throughout this unit in the mine area." We concur with this statement. It is very likely that highly permeable zones, or at least zones with hydraulic conductivities over 1.5 or 2 ft/day will be exposed during mining. Such permeable zones will contain much more groundwater than the typically modeled sediment with the low hydraulic conductivity. Without knowing specifically where such zones exist, they cannot be accurately modeled. Without being accurately modeled, the model cannot give accurate result on a site-specific basis.

Uncertain Recharge and Possible Calibration Issues

Besides the scale issue, the results of the model are questionable because it was built and calibrated using suspect recharge numbers. Recharge from precipitation is the primary source of groundwater in the subject area. So consequently, it is also a major model input. In a steady-state case, the total amount of water leaving the model equals the amount of recharge entering the model. It is not surprising that the Arcadis sensitivity study shows the model is very sensitive to recharge.

Yet, the model was calibrated using a suspect amount of recharge. In their groundwater model report (page 12), Arcadis states: "as indicated in the baseline reports, site annual precipitation is on average 47 (44 to 50) inches/year of which approximately 12 inches/year (or 27%) recharge groundwater." They adjust recharge slightly during calibration, dividing the applied recharge into two zones averaging 11.9 inches over the active mine area. However, the baseline reports reviewed for this study do not quantify the amount of recharge. Rather, they estimate the amount of evapotranspiration at 27% of the annual precipitation, or about 12.2 inches (Riverside, 2009, p. 3-11). The only mention of recharge in the two Riverside baseline reports is a discussion of the sources of recharge to the various hydrostratigraphic units in the groundwater flow description section of the groundwater baseline report (Riverside, 2010).

An error in the model calibration indicated the average recharge should be higher. Arcadis used average wintertime base flows from the streams as a calibration target (Arcadis, 2013, p. 19). While the wintertime base flows are the low flows, they do not represent the steady-state base flow which is the average base flow over a long period of time. The steady-state base flows, which should have been the calibration targets, are larger than the wintertime base flows. To achieve higher steady-state base flows during calibration, more recharge would be required.

For the predictive simulations, the recharge is applied seasonally, but the total annual amount was not changed from the calibration. If the recharge applied during calibration was too low, as implied, than the recharge applied in the predictive simulations was also too low. Therefore, the predictive simulations likely do not accurately predict the groundwater extraction volume needed.

Poor Conceptualization of Depressurization in the Sub Red 1 Sand

One last reason provides doubt into the accuracy of the groundwater extraction volumes. We believe the way depressurization of the Sub Red 1 Sand was simulated in the model underestimates the extraction volume required from the Sub Red 1 Sand.

In Arcadis' model, depressurization of the Sub Red 1 Sand is simulated by using both drain cells in the Sub Red 1 Sand at the active excavation and depressurization wells away from the active excavation. The use of drain cells is conceptually inaccurate because during real-world mining, the Sub Red 1 Sand will not be exposed. Therefore, passive inflow of groundwater to the excavations will not directly occur from the Sub Red 1 Sand, and all depressurization will need to occur through the pumping of wells.

In the model, the required depressurization is achieved by drawdown in the Sub Red 1 Sand created by both the drain cells and the depressurization wells. To achieve the same amount of drawdown in the Sub Red 1 Sand that is supplied by the drain cells, the depressurization wells would need to be pumped at a higher volume. Therefore, the volume of water extracted from the Sub Red 1 Sand in the model to achieve the required depressurization, the sum of the water produced by the drain cells and the wells, is less than the amount that will need to be produced in the real world when only wells are used.

Minimizing Effects through Sequencing Excavations (Question B)

The second question is whether the analyses and results in the reviewed documents describe the geographic extent of the drawdown with enough precision to assess the feasibility of sequencing the mining excavations to minimize project effects.

The project's effect on streams comes largely from two sources: dewatering drawdown (both passive and active) in the Glacial Drift and Alluvium unit and the active mining physically removing/replacing portions of the stream basins (a large portion of 2003 basin, but also small parts of the 2002 and 2004 basins) and the stream 2003 channel. Drawdown will reduce the groundwater contribution to streamflow. Physical mining of the basins will change the runoff contribution to streamflow. The question here deals with the drawdown component.

The reviewed documents do not address potential alternative sequencing of mining excavations. The groundwater modeling report by Arcadis presents the proposed mining plan with 25 years of sequential mining excavations which generally, for the first 10 years, work the central portion of the mine area, and then extend to the outer edges of the mine area in later years (see Figure 36 in Arcadis, 2013). The predictive simulations run by Arcadis use this mine plan and no other. If alternative plans were simulated, the results are not presented. Similarly, the water management plan (Tetra Tech, 2013) also appears to look at a single mining plan.

In the groundwater model report, drawdown is only presented for years 8 and 25 of mining, for its maximum extent (during any of the 25 mining years), and as long-term, post-mining residual drawdown. The report text and these figures do not provide enough detail to assess how drawdown changes throughout the sequencing of mining excavations.

Predicted base flow reductions are more thoroughly presented, with graphs of base flow reductions from pre-mining through 50 years post mining and as maps of percentage stream depletion for every 5 years from year 5 to year 75. Therefore, while sequential change in drawdown are not well presented, the sequential changes in predicted impact from the drawdown to streamflow is.

We have reason to believe (as explained in the answer to question C) that the presented sequencing of excavations does correctly show the impacts to streamflow assuming the recharge is correct. If the recharge is incorrect, as is likely, the impacts are also likely incorrect. Whether the impacts could be minimized by alternative mining sequences was not investigated.

Drawdown's Effect on Surface Waters (Question C)

The third question asks whether the analyses and results in the reviewed documents describe the geographic extent of the drawdown with enough precision to assess the effects of aquifer drawdown on surface waters outside the mine's surface disturbance footprint.

As mentioned above, the project's effect on streams comes largely from two sources: dewatering drawdown in the Glacial Drift and Alluvium unit and the active mining physically removing/replacing portions of the stream basins and the stream 2003 channel. The question here deals with the drawdown component outside the active mine area and how that drawdown affects the groundwater contribution to streamflow.

As explained in the answer to question A, we believe the model may not be sufficient to accurately predict the groundwater yields from each sequential excavation. This is partially due to lack of detail in the model necessary for the model to accurately predict site-specific conditions. However, the reduction in streamflow from dewatering drawdown is a less site-specific phenomenon than the dewatering yield for a specific excavation. In that regard, the model may be adequate, at least in terms of scale and included detail, to more precisely predict impacts to streamflow than dewatering volume. The reduction in groundwater contribution is due to the change in aquifer gradient (by drawdown) over the effected length of stream reaches rather than at a specific point. The amount of required drawdown is dictated by the mining plan – it will be the same no matter how much dewatering volume is required. Consequently, the gradient resulting from dewatering will not radically change outside the mine footprint. Thus, the streamflow reduction should not be very sensitive to dewatering volume.

However, also as explained for question A, we suspect model results may be incorrect due to unsupported recharge estimates. If the recharge is incorrect, the model is improperly calibrated and the hydraulic conductivities assigned in the Glacial Drift and Alluvium are at least partially wrong. Since hydraulic conductivity affects gradient, and thus the groundwater contribution to the streams, the predicted impact to the streams may not be correct if the applied recharge is incorrect.

There is another issue to consider: that of the groundwater contribution from the Sub Red 1 Sand. The conceptual models by both Riverside (2010) and Arcadis (2013) show most the groundwater contribution to the streams comes from the glacial drift and alluvium. However, there is also a contribution to Lone Creek (stream 2002) from the Sub Red 1 Sand. This contribution will be reduced by the proposed mining due to required depressurization. The model predicts a drawdown in the Sub Red 1 Sand in the known reach of Lone Creek which receives inflow from the Sub Red 1 Sand of between 10 and 160 feet. As explained in the answer to question A, additional water may need to be produced from the Sub Red 1 Sand than was modeled. If this requires additional wells not simulated in the model, it could affect the drawdown pattern and, thus, change the predicted impact to Lone Creek.

Another consideration for the Sub Red 1 Sand is that the model improperly reflects drawdown in the unit at the model's northern boundary. For the layer representing the unit, the northern model boundary is set as a no-flow boundary, representing a regional groundwater flow line. Drawdown in the model reaches this boundary (Arcadis, 2013, p. 30), which violated the no-flow nature of the boundary. In reality, the drawdown will extend further north than the model boundary into the Scarp Creek basin. If the Sub Red 1 Sand crops out in that basin, it is possible flow will also be reduced to Scarp Creek. This possibility was not investigated.

There is also a small possibility that drawdown from glacial drift extends to or beyond the assumed groundwater divide between the Lone Creek and Scarp Creek basins. No water level data is presented in any of the reviewed reports for the Scarp Creek basin, so the location of the assumed groundwater divide is based on the topographic divide, which is relatively close to the active mine area. The presentation of drawdown in the modeling report does not show drawdowns less than ten feet. Figure 63a of the report shows ten feet of drawdown in the glacial drift about 2,500 feet from the topographic divide between Lone and Scarp Creeks, so it is possible drawdown does extend to or across the divide. If this is the case, it will cause at least a small reduction in Scarp Creek base flow because the gradient driving groundwater inflow to the creek will be reduced.

Recharge Periods for Sequential Excavations (Question D)

The final question asks if the analyses and results in the reviewed documents describe the geographic extent of the drawdown with enough precision to predict the aquifer recharge period for each sequential excavation.

The proposed mine plan shows each sequential excavation is adjacent to the previous excavation (see Figure 36, Arcadis, 2013). Because of the close proximity of each sequential excavation, the dewatering for each new excavation will also greatly affect the previous excavation. So recovery of water levels in each excavation will be relatively minor for at least a couple years following the refilling of the excavation. The effect can be seen on Figure 65 from the Arcadis report which shows hydrographs in the Glacial Drift and Alluvium unit over the life of the mine. Much of the recovery will not occur until dewatering is complete at the end of mining.

Further, the model as constructed (and assuming it does not have the problems discussed above), cannot accurately predict recovery in any particular excavation while mining is occurring. This is because the predictive simulations done were actually completed with two separate models: a model with pre-mining conditions and a model with post-mining conditions. The pre-mining model, which was also used for mining conditions, uses the calibrated hydraulic conductivities. The post-mining model, for the area of the active mine, uses modified hydraulic conductivities for layers 2, 3 and 4 in the mine areas backfilled.[24] In the real world, as each new excavation is dug, the previous one will be backfilled. Since the model does not represent the change in hydrologic properties for the backfill until the whole mine is backfilled, it cannot reliably predict recovery in the backfilled areas until mining is completed. For the model to more accurately predict recovery after each sequential excavation, the hydraulic conductivity of each area backfilled should also be changed sequentially.

Arcadis (2013, p. 33) states that full recovery occurs by year 50 (or 25 years after the end of mining). However, based on Figure 70 in their model report, "full recovery" includes permanent, residual drawdowns of up to 65 feet in the 2003 basin (as well as other areas with water levels 45 feet higher than under pre-mining conditions). So in a very real sense, the model predicts recovery to pre-mining conditions will never happen, at least in terms of water levels.

In terms of streamflow reductions, the model as constructed, predicts base flow in stream 2004 will recover to pre-mining levels, will permanently decrease slightly in stream 2002, and

[24] In our opinion, it probably should have used modified conductivities for layer 1 as well (see point 12 of summary discussion on the groundwater modeling report).

will permanently increase slightly in stream 2003 (Arcadis, 2013, p. 34) – though reaches of stream 2003 in the mine area will have permanent decreases (Arcadis, 2013, p. 34-35 and Figure 80).

All this recovery, of course, is predicted by a model with several flaws as described above. The most pertinent to the question of recovery is the suspect recharge used in the model. If recharge is actually greater than modeled, recovery will occur quicker than predicted. If it is smaller, it will take longer. The uncertainty in recharge in the model creates much uncertainty in the length of the recovery period.

Recommendations to Address Gaps in Data and Analyses

Several data and analyses gaps and flaws have been described in this review. The following are recommendations to address those gaps.

1. There is much uncertainty in exactly how much precipitation the mine site (and model area) receives. The on-site precipitation record should be improved by collecting at least several more years of data. Concurrent stream gaging records should be collected at the same time. Once several more years of actual data is established, the precipitation data can be compared with other nearby, long-term stations to establish regression relationships between the stations. Based on those relationships, a long-term, average precipitation for the mine site can be established.

2. The difference in evapotranspiration estimates between Riverside (2009 and 2010) and Tetra Tech (2013) should be examined. If necessary, an on-site evapotranspiration study could be conducted.

3. Long-term stream hydrographs should be subjected to hydrograph separation analysis to establish more reliable steady-state base flow estimates.

4. Using the results from the recommendations above, a true estimate of the average annual recharge should be made.

5. Better monitoring of well water level records should be established through the use of pressure transducers and data loggers in at least several wells in each hydrostratigraphic unit. These records should be made concurrently with the recommended precipitation record (#1 above) so that a better relationship between water levels and precipitation can be established.

6. Model boundaries should be extended so that predicted drawdown does not reach any no-flow boundaries.

7. Recharge zonation should be added to the model that represents the noted orographic effect and the relative infiltration ability of the surface geology.

8. Consideration should be given to revising the model to separate out the sand and gravel within the Lower Mineable Coal Sequence as a separate hydrostratigraphic unit/model layer. Similar consideration should be given to the clay unit above the Sub Red 1 Sand.

9. To reduce uncertainty in the hydrologic properties of the glacial drift, a more in-depth examination of the borehole data from wells drilled through the glacial drift should be accomplished to look for additional high permeability zones. If necessary, new wells

should be drilled in areas lacking in data. The model should be modified based upon the results.

10. Consideration should be given to using a finer grid spacing in the model for the active mine area if the current grid size is close to the minimum size of the planned excavations, particularly if recommendation 9 leads to more detail in the glacial drift.
11. Several monitor wells could be drilled in the Scarp Creek basin to establish the groundwater divide in the water table between it and the 2002 basin. Consideration should be made to extending the active model into the Scarp Creek basin.
12. The model should be recalibrated following implementation of the above recommendations. Improved steady-state water level targets can be developed from the improved water level monitoring. Steady-state base flows should be used as targets instead of winter base flows.
13. The hydraulic properties of the backfill materials should be better investigated. In particular, consideration should be given to whether glacial drift and alluvial backfill has different properties than undisturbed materials.
14. The model should be modified so that backfill properties are sequentially added during the mining simulation rather than all at the same time at the end of mining.
15. During the mining simulation, drain cells should not be used for depressurization of the Sub Red 1 Sand.
16. Several different mining excavations could be examined with the model to examine if the modification of the sequencing could minimize stream impacts.
17. The model report could have more complete documentation, including discussion and support for the amount of recharge used, a water balance by model layer, more usable scales on some of the figures, and a discussion of the stress periods and time stepping used.
18. Additional background groundwater quality is needed, particularly from the glacial drift and alluvium.
19. The water management plan should be modified to use the revised model results, as well as the improved precipitation, evapotranspiration, base flow, and recharge estimates (recommendations 1 – 4).

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